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Effect of Masker Duration on the Detectability of Pulsed Diotic and Dichotic Tonal Signals

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EFFECT OF MASKER DURATION ON THE DETECTABILITY OF PULSED
DIOTIC AND DICHOTIC TONAL SIGNALS

by

Theodore H. Miller

A Thesis Submitted to the Faculty of the Graduate School of
Loyola University in Partial Fulfillment of
the Requirements for the Degree of
Master of Arts

February

1972

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CHAPTER ONE

INTRODUCTION

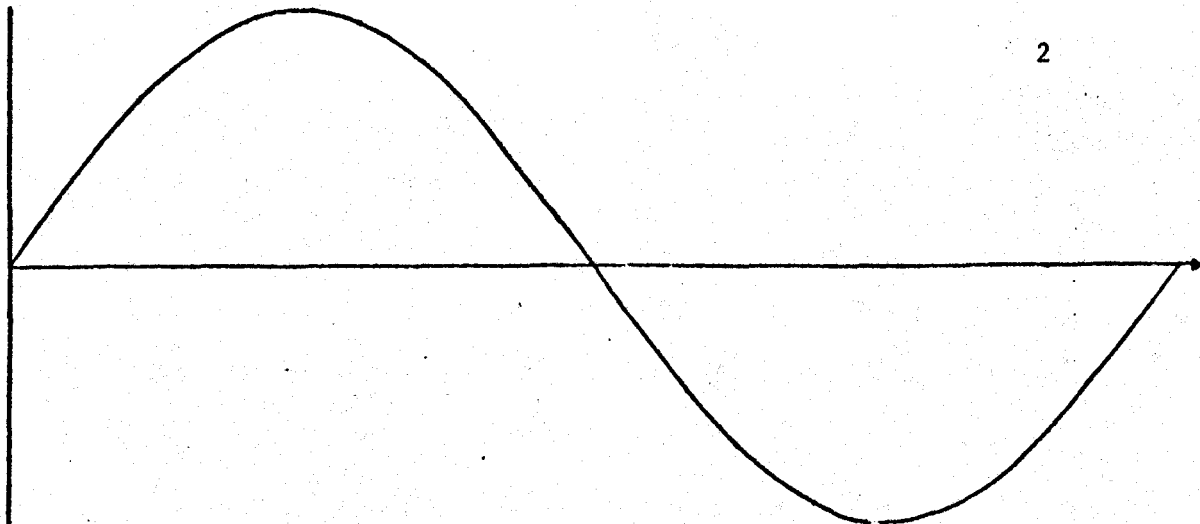
Auditory masking is the process by which the detectability of one sound, the signal, is adversely affected by the presence of another sound, the masker. If a tone and a noise are presented monaurally (to one ear), for instance, the tone may be masked; that is, the "threshold"¹ for the tone in the presence of the noise is greater than the threshold for the tone alone. In this case the ear (monaural auditory system) has classically been thought to differentiate between the signal-plus-noise configuration and the noise alone on the basis of an energy difference (Fletcher, 1929).

For a long time the binaural system was viewed as simply a combination of two monaural systems when engaged in such a detection problem. Each ear was thought to analyze its input separately. An interesting phenomenon, however, invalidated this hypothesis. If a signal and a noise were presented to one ear, and the level of the signal adjusted so that it was just inaudible, the addition of the same noise without the signal to the other ear made the signal again clearly detectable. The threshold for a monaural signal masked with noise at both ears, then, was lower than that for a signal masked at only one ear. Thus, the view of the binaural system as a simple combination of two monaural systems could not account for the facts of binaural analysis.

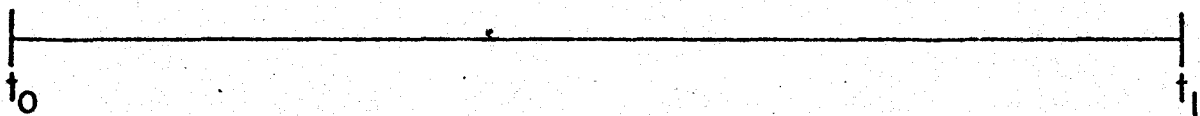
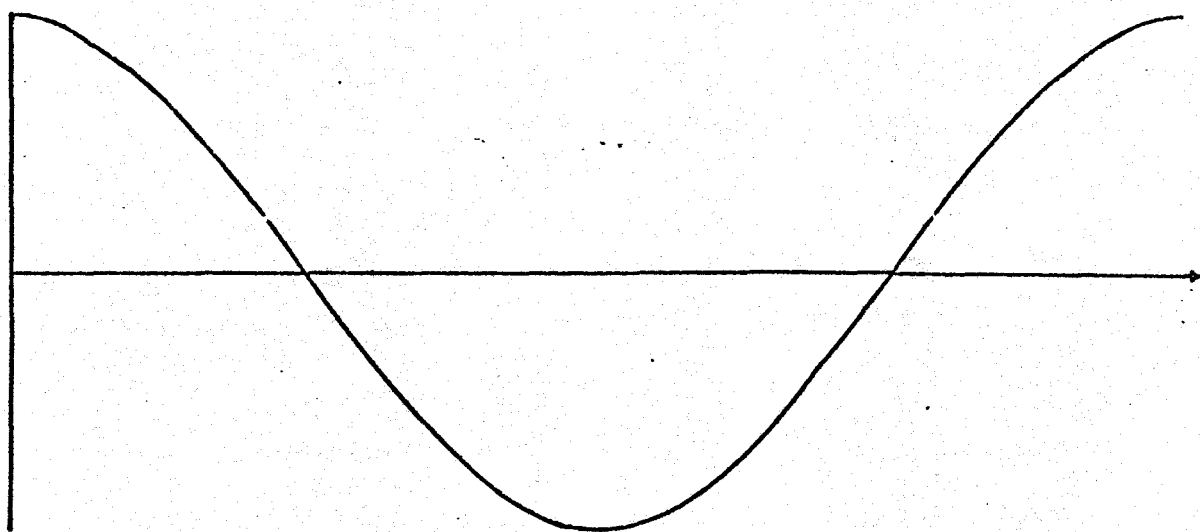
Historically, the study of binaural masking began when Hirsh (1948) investigated the effect of interaural phase² (the relation of the phase of a waveform at one ear to the phase of a waveform at the other ear) on binaural masking. He was interested in the amount of masking of a pulsed

FIGURE 1: Two sinusoids of equal amplitude and frequency which are 90 degrees out of phase. Waveforms a and b are plots of sinusoidal pressure change having the same amplitude and frequency. Each undergoes one complete cycle (360 degrees or 2π radians) of change during the time period from t_0 to t_1 . However, at every instant from t_0 to t_1 , the phase of waveform a is one quarter cycle (90 degrees or $\pi/2$ radians) behind that of waveform b.

a



b



tonal signal which would be caused by the presence of a continuous noise masker. Hirsh considered two interaural phase relations between the signal (S) at one ear and the signal at the other ear and between the noise (N) at one ear and the noise at the other ear. These interaural phase relations were: signal and noise waveforms in-phase at the two ears (S_o and N_o respectively) and signal and noise waveforms 180 degrees out-of-phase at the two ears (S_π and N_π respectively). By combining interaural phase relations of the signal and noise waveforms, Hirsh obtained various conditions such as $N_o S_\pi$, $N_\pi S_o$, $N_\pi S_\pi$, etc. He also employed a control condition in which the signal and noise were presented to only one ear ($N_m S_m$). Hirsh's results indicated that the greatest amount of masking was obtained in either the monaural condition ($N_m S_m$), or in those conditions in which the interaural phase relation of the signal was identical to the interaural phase relation of the noise ($N_o S_o$ and $N_\pi S_\pi$). The least amount of masking occurred in those conditions in which the interaural phase relation of the signal was different from the interaural phase relation of the noise ($N_\pi S_o$ and $N_o S_\pi$). The difference between the amounts of masking obtained in these two types of conditions has since been referred to as the masking level difference, or the MLD.

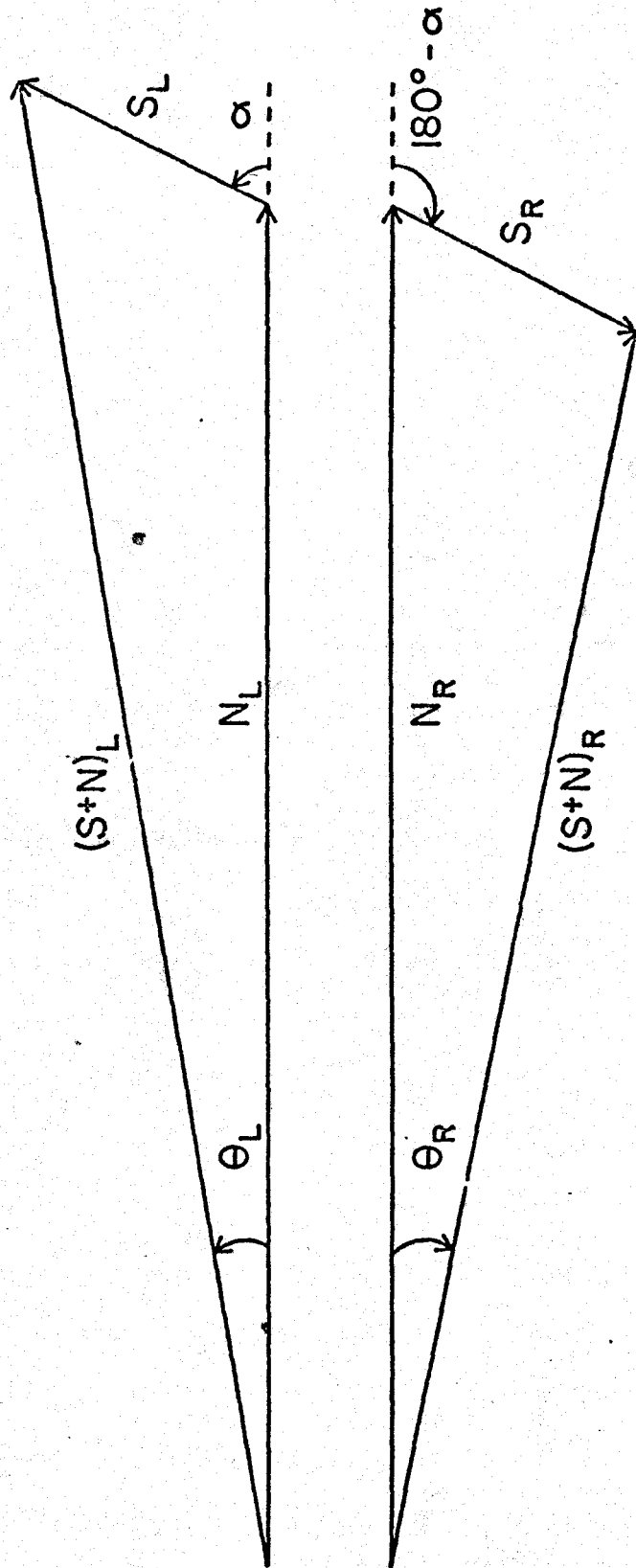
There have been two explanations proposed for the added advantage that the binaural system may exhibit over the monaural system when detecting a tonal signal in a background of noise. One of these, the Webster-Jeffress hypothesis (Webster, 1951; Jeffress, Blodgett, Sandel, and Wood, 1956; Jeffress, to be published) considered the time transform of the interaural phase shift caused by the addition of the signal to the noise to be the relevant cue for the binaural system. The other

explanation, The Durlach Equalization-Cancellation model (Durlach, 1960, 1963, 1964; Colburn & Durlach, 1965), placed the emphasis on the power difference between the waveforms at the two ears. Since both models make similar predictions for the masking conditions studied in this paper, both will be examined briefly.

Webster formulated the hypothesis that, in situations in which an interaural phase difference exists, the addition of the signal to the masker causes the combined waveform to lead in one ear and lag in the other. In other words, the addition of the signal produces a time shift between the waveform at one ear and the waveform at the other ear. In such "antiphasic" conditions (those in which the interaural phase relation of the signal is different from the interaural phase relation of the noise), the binaural system has additional information to employ in the detection of the signal. This cue is not available in the "homophasic" conditions (those in which the interaural phase relation of the signal is identical to the interaural phase relation of the noise). This added information, Webster suggested, results in the MLD obtained in the antiphasic conditions relative to the homophasic conditions.

Jeffress elaborated on this hypothesis and presented a vectorial representation of the binaural analysis involved (see Fig. 2). The stimulus situation represented in this diagram is the $N_0 S_\pi$ condition. The masking noise to the right ear and to the left ear is represented by the horizontal vector, N_R and N_L , while the tonal signals to the right and left ear are represented by the vectors, S_R and S_L respectively. The noise component is in-phase at the two ears while the signal component is reversed 180 degrees in-phase at one ear relative to the other. The length of the vectors represents the intensities of the signal and noise

FIGURE 2: Vectoral representation of the $N_0 S_\pi$ condition. The upper triangle represents the stimulus waveform to the left ear and the lower triangle the stimulus waveform to the right ear. Vectors N_L and N_R represent the in-phase noise components of these waveforms and vectors S_L and S_R the 180 degrees out-of-phase signal components of these waveforms. Angles α and $180^\circ - \alpha$ represent the phase angles at which the signal component is added to the noise component for each ear. Vectors $(S+N)_L$ and $(S+N)_R$ represent the resultant waveform to the respective ears. In all cases the length of the vectors represents the intensity of the stimulus. Angles θ_L and θ_R represent the intra-aural phase shifts for the respective ear caused by the addition of the signal to the noise. The sum of θ_L and θ_R (θ) is the interaural phase shift responsible for the time shift of primary importance to the Webster-Jeffress hypothesis.



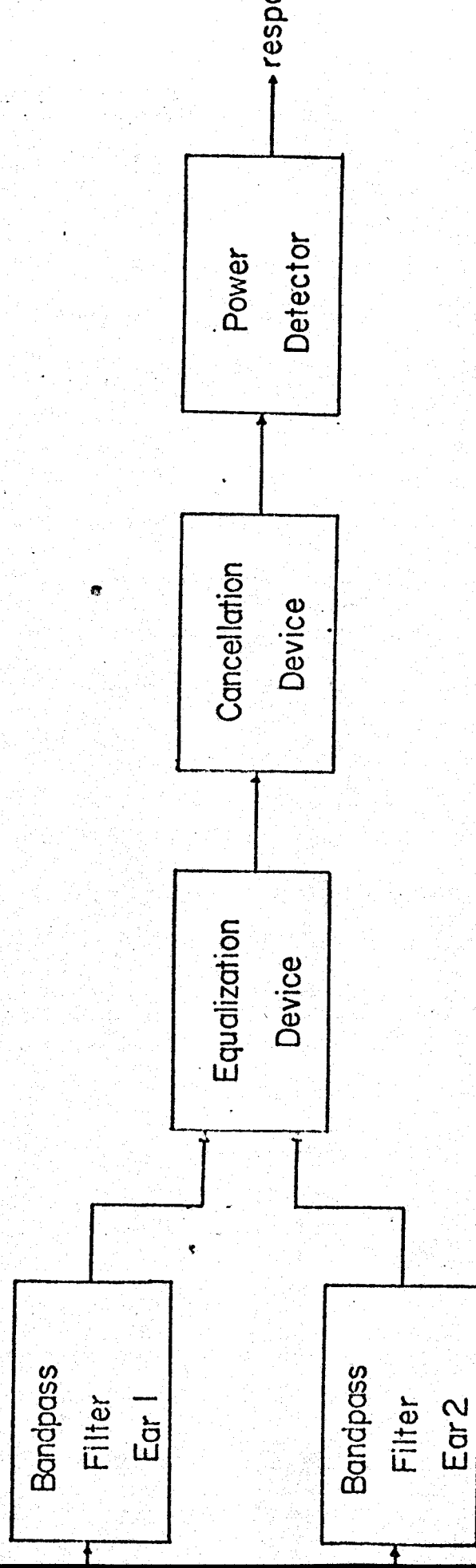
components. The signal is added to the noise at the two ears at the angles, α and 180 degrees $-\alpha$ respectively. The resultant waveform comprised of both signal and noise to the right ear is represented by the vector, $(S+N)_R$, and the resultant waveform to the left ear is represented by the vector, $(S+N)_L$. The interaural phase shift caused by the addition of the signal to the noise is represented by the sum of the two angles, θ_R and θ_L . A time transform of this phase shift between the signal-plus-noise in one ear and the signal-plus-noise in the other ear is the time shift of primary importance to the Webster-Jeffress hypothesis.

Jeffress proposed that θ , the sum of θ_R and θ_L , corresponds to a point in a neural delay line between the two ears where the inputs from the two ears coincided. Addition of the signal to the noise moved this point of coincidence away from that associated with the noise alone. The larger the interaural phase shift (θ), the greater the movement and the more easily detectable it became. However, the model assumes that there are small fluctuations in this point of coincidence ("neural noise") even when no signal is present in the noise. These fluctuations may be viewed as a source of error in the operation of the binaural system in detection problems, since they may either add or subtract from the magnitude of the phase shift caused by the addition of the signal to the noise. Since the magnitude of the MLD for any masking condition is dependent upon the size of the interaural phase shift, θ , these fluctuations add a small amount of variance to the size of the difference in performance between the homophasic and antiphase conditions. Taking this factor into consideration, the Webster-Jeffress model is able to represent any monaural or binaural masking condition in terms of vector diagrams.

The second major explanation of binaural phenomena in masking is the Durlach Equalization-Cancellation model. In a series of papers, Durlach proposes a quantitative "black box" model for use in interpreting data on binaural MLDs. The essential elements of this model as schematized in Fig. 3 are: a pair of filters for the two ears, an equalization device, a cancellation device, and a power detector. The input is filtered at each ear and is then channeled into the equalization device. This device attenuates and/or delays the input in one ear relative to the input in the other ear until the waveforms are the same in both ears. The cancellation device then subtracts one waveform from the other. Prior to the onset of the signal, if the noise at both ears were identical (N_o), the cancellation device would eliminate the input waveforms and the power detector would yield zero resultant. If the signal were the same at both ears (S_o), it too would be eliminated and the remaining power would still be zero. If, however, there were an interaural signal or noise disparity, the cancellation process would not entirely eliminate the inputs and this difference would be reflected by the power detector.

It should be noted that as the E-C model has been described thus far, it predicts perfect detection in the antiphasic ($N_o S_\pi$ or $N_\pi S_o$) conditions. Since humans do not exhibit perfect performance in such detection situations, provision for two sources of error has been made in the Durlach model to account for the masking data. These two error terms are introduced in the form of "jitter" in the equalization process in the amplitude and the temporal domains thus preventing complete equalization of the input waveforms. Modified in this manner, the Durlach model can accurately account for the relative changes in magnitude of the MLDs obtained under various conditions of interaural phase and intensive disparity.

FIGURE 3: A block diagram of the essential elements of the Durlach Equalization-Cancellation model. The hand-pass filters at the two ears filters the input before it enters the equalization device. This device attenuates and/or delays one waveform relative to the other until they are equalized. The waveforms are then subtracted by the cancellation device. The output of this device is then analyzed by the power detector and the appropriate response is made based on the outcome of this analysis.



Most of the investigations of binaural masking have employed continuous noise as the masker and a gated tone as the signal (Hirsh, 1948; Hirsh & Webster, 1949; Webster, 1951; Jeffress et al., 1956). McFadden (1966), however, studied the effects of continuous versus pulsed noise maskers in homophasic and antiphasic conditions. He used a 400 Hz tone of 125 msec duration as the signal and a wide-band thermal noise as the masker. In the pulsed condition, the noise and the signal onsets and offsets were simultaneous. He found that in the homophasic condition, $N_O S_O$, the amount of masking caused by the pulsed noise was the same as that caused by the continuous masker. Performance in the antiphasic conditions, $N_O S_\pi$ and $N_\pi S_O$, however, was affected considerably by the pulsed presentation of the masker. The amount of masking in the antiphasic conditions with this pulsed presentation of the masker was greater than that in the continuous masking condition resulting in a smaller MLD.

In the second part of this study, McFadden investigated the effect of extending the duration of the masker forward in time (prior to the onset of the signal) from the pulsed condition just described. Therefore, the masker and tone offsets occurred simultaneously, but the onset of the masker preceded the onset of the tone. He reasoned that these conditions should yield MLDs of a magnitude somewhere between those of the pulsed and continuous masker conditions. His results showed that the MLDs increased from about 12 dB at 0 msec of forward "fringe" to about 15 dB at 600 msec of fringe. At this point the rate of increase declined and the MLD slowly increased until at about 1000 msec of fringe the MLD was the same as those obtained in the continuous condition. In these first two experiments, McFadden employed a single interval "YES-NO" procedure in which the observer's task on any particular trial was to state whether or not the

signal had been present in addition to the noise.

In the third part of this study, in addition to the "YES-NO" procedure, McFadden used a two alternative temporal forced-choice (2ATFC) procedure in which the observer's task was to indicate which of the two observation intervals contained the signal. The interaural phase conditions studied in this experiment were the homophasic and antiphasic conditions (N_0S_0 and N_0S respectively). Under both phase relations, continuous and pulsed maskers were used separately to mask a 125 msec 400 Hz tone. Performance under the homophasic conditions as measured by either the "YES-NO" or 2ATFC procedures was not differentially affected by the continuous or pulsed presentation of the masker. Performance under the antiphasic conditions, however, was worse in the pulsed masker situation than in the continuous masker situation. Performance under the continuous antiphasic masker condition was the same whether measured by the "YES-NO" or the 2ATFC procedure. Performance under the pulsed antiphasic masker condition, however, was slightly poorer as measured by the "YES-NO" task than as measured by the 2ATFC task. Thus, when pulsed noise maskers were used, the 2ATFC procedure yielded a larger MLD than did the "YES-NO" procedure.

McFadden explained the "fringe" results of this study in relation to the Webster-Jeffress hypothesis. He suggested that the continuous noise condition provided the binaural auditory system with a baseline or reference phase prior to the onset of the signal. Thus, at the onset of the signal, the resultant phase shift (θ) was from a known interaural phase to an interaural phase relation that was dependent upon the characteristics of the signal. In the pulsed masker condition, however, there was no interaural phase relation prior to the onset of the signal since there was no noise alone. The noise and the signal were added prior to presentation

so that the phase shift caused by the simultaneous presentation of the two waveforms was not away from a reference phase and was therefore less discernable. As the duration of the fringe in the second part of the study was increased, the phase shift became more discernable. At about 600 msec of forward fringe, the pulsed masker condition and the continuous masker condition yielded similar enhancement. In the discussion of the results of the third part of his study, McFadden used a similar explanation for the differences in performance under the antiphasic pulsed masker conditions as measured by the two difference procedures, the "YES-NO" task and the 2ATFC task. Since the observer received the noise burst on every trial of the 2ATFC procedure, the phase characteristics of the noise may have been more familiar to him than they were in the "YES-NO" task. This may have resulted in a more discernable phase shift when the signal-plus-noise waveform was presented and, therefore, led to higher detectability and a larger MLD.

In a more recent study investigating backward masking, Dolan and Trahiotis (1972) used a masking noise of fixed duration (75 msec) to mask an 8 msec tone in order to determine the effect of various temporal relations between signal and masker on the MLD ($N_0 S_0$ relative to $N_0 S_\pi$) as measured with a 2ATFC paradigm. They varied the temporal relations between the tonal signal and the noise masker by delaying the onset of the noise by some amount, Δt , relative to the onset of the signal. One of their conditions, $\Delta t = 0$, is comparable to the pulsed masker condition studied by McFadden except for the 67 msec of masker occurring after the offset of the signal. It is interesting to note, however, that the size of the MLD obtained by Dolan and Trahiotis in this condition was 20 dB whereas McFadden's pulsed masker condition yielded a MLD of only 12 dB.

Even though it has been shown that as the duration of a tonal signal decreases, the magnitude of the MLD increases (Blodgett, Jeffress, & Taylor, 1958), and that the 2ATFC paradigm yields larger MLDs than does the "YES-NO" procedure, a MLD of the magnitude obtained by Dolan and Trahiotis would not be expected since the maskers used in their conditions were non-continuous and, unlike those used by McFadden, had no forward fringe. Evidently, then, the occurrence of part of the masking noise after the offset of the signal in the Dolan and Trahiotis study may have acted much like the forward fringe in the McFadden study.

These data may be interpreted as evidence that the binaural system uses the occurrence of the masking noise after the offset of the signal to provide a baseline or reference phase similar to that discussed by McFadden (1966). The phase shift of the signal-plus-noise waveform might become more apparent and result in higher detectability and a larger MLD. The present study is an attempt to determine to what extent the occurrence of masking noise after the offset of the signal does, in fact, improve performance in a detection task. This possible advantage is investigated by varying the amount of noise occurring after the offset of the signal while keeping the masker and signal onsets simultaneous.

CHAPTER TWO

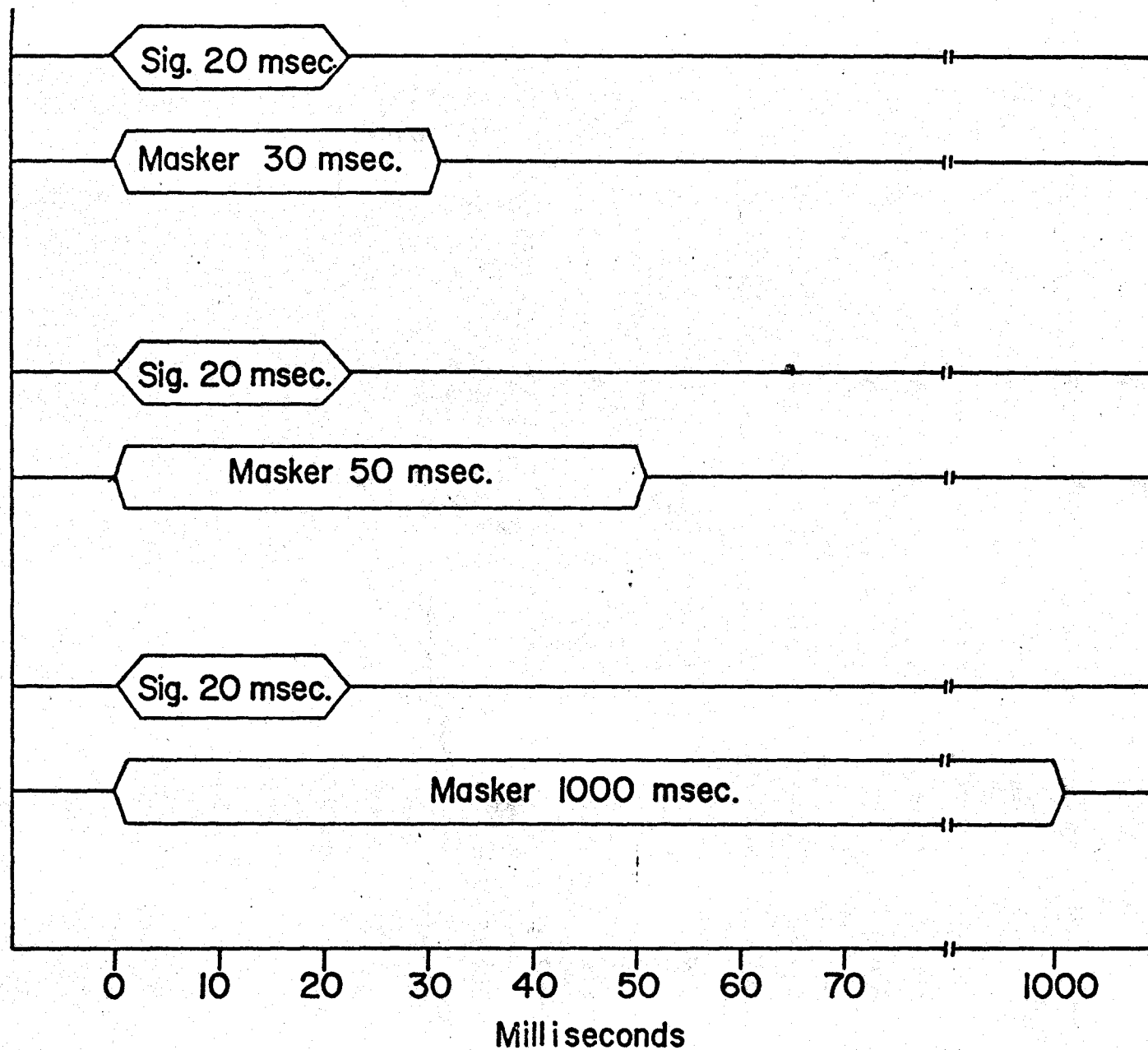
PROCEDURE

The binaural masking conditions investigated in this study are the homophasic ($N_0 S_0$) condition and the antiphasic ($N_0 S_\pi$) condition. Three of the six temporal relations between signal and masker considered in this study are shown in Fig. 4. In all conditions the signal duration used was 20 msec with a 2.5 msec rise-fall time. Masker duration, however, was varied in each condition with durations of 30, 50, 250, 500, and 1000 msec being employed. In addition, a continuous masking condition was employed. The size of the MLD ($N_0 S_0$ relative to $N_0 S_\pi$) was measured as a function of masker duration.

To measure performance in each masking condition and to determine the magnitude of improvement in the antiphasic condition relative to the homophasic condition, a two-alternative temporal forced-choice (2ATFC) technique was used. The observer's task was to state in which of two observation intervals the signal had occurred. Each trial consisted of the following temporal sequence: warning light (0.4 sec), pause (0.4 sec), light for the first observation interval (0.02 sec), pause (0.4 sec), light for the second observation interval (0.02 sec), response interval (1.5 sec), and "feedback" interval (0.2 sec). The lights used to designate the intervals were spatially and temporally discrete. The signal occurred on every trial with equal probability of occurrence in each interval. The feedback light informed the observer after each trial which of the two intervals had contained the signal.

The measure of performance for each masking condition was the average

FIGURE 4: Three of the six temporal relations of the signal and the noise investigated in the present experiment. In all conditions a 20 msec 500 Hz tone was employed. In addition to the masker durations of 30, 50, and 1000 msec shown here, 250 msec, 500 msec, and continuous maskers were also employed. Rise fall times were 2.5 msec for the signal and 1 msec for the noise masker.



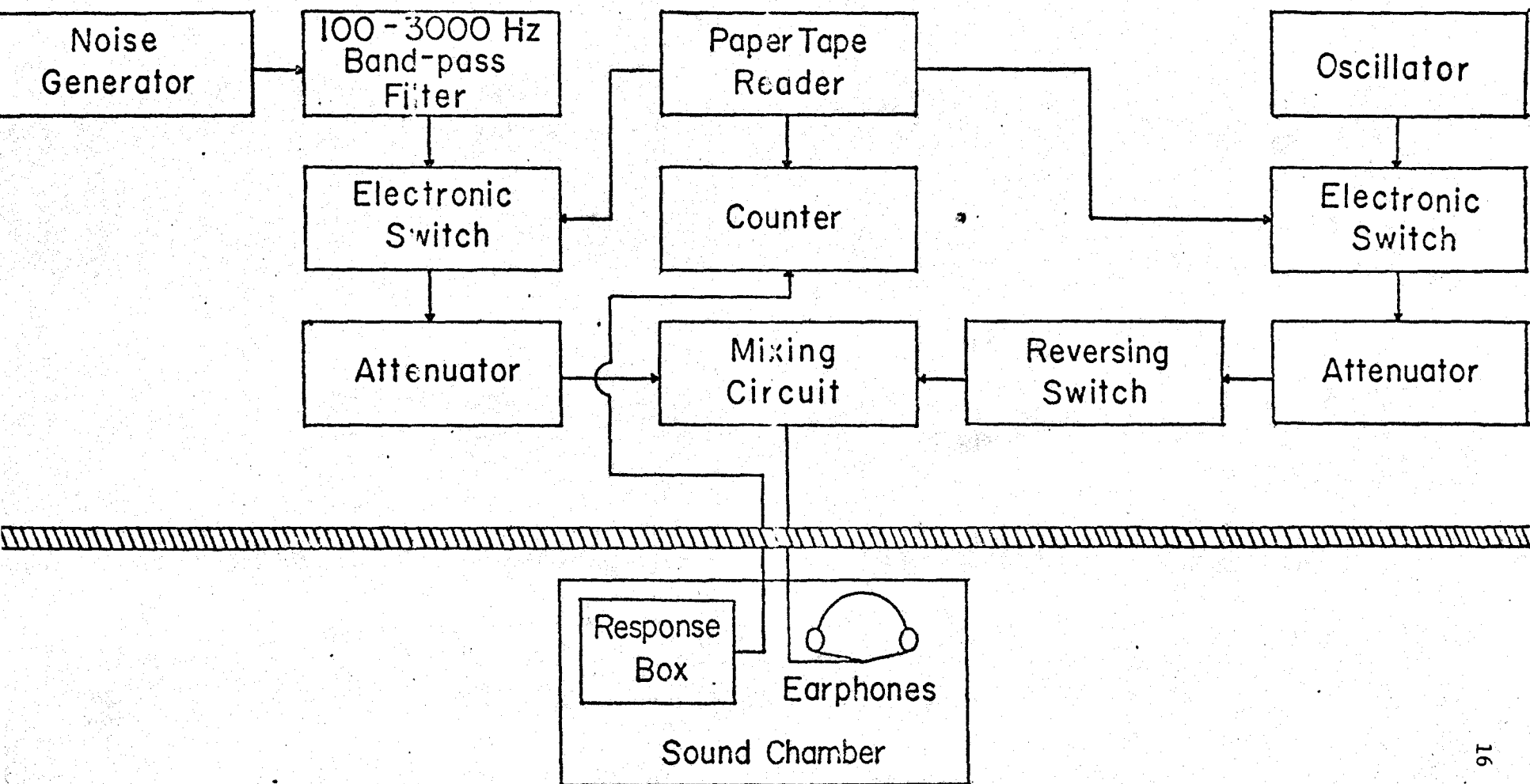
percent correct, $P(c)$, for intervals one and two computed for 400 trials at each of two signal-to-noise ratios. From these data two-point psychometric functions (functions relating percent correct to signal energy) were generated for each observer at each temporal relation for the homophasic and the antiphase conditions. These psychometric functions were fitted by the equation, $d = m(E/N_0)^k$, where E is the energy of the signal, N_0 is the noise power per unit bandwidth, and m and k are constants. d' was transformed to $P(c)$, (E/N_0) was transformed to $10 \log (E/N_0)$, and the best fitting values of m and k were selected by eye. A more detailed description of this procedure has been reported by Egan (1965).

The masker in the present study was a pulsed band-pass noise, 100-3000 Hz, with a spectral level of 50 dB SPL and a rise-fall time of 1 msec. The signal was a 500 Hz tone.

The equipment used for the presentation of the stimuli and for recording responses is schematized in Fig. 5. A Grason-Stadler 455-C noise generator was used as the noise source. The signal was generated by a General Radio model 1310-B oscillator. After the noise was filtered through a model 302 Spencer-Kennedy Laboratories electronic filter, both the signal and the noise were gated through electronic switches, and the signal was passed through two Hewlett-Packard attenuators. The noise and the signal waveforms were then mixed and the total waveform presented through dichotically wired Grason-Stadler TDH-49 earphones to the observers who were seated in an IAC soundproof chamber. The observer's responses were recorded automatically.

The four observers used in this experiment were either members of the staff of the Parmlly Hearing Institute or students at Loyola University having clinically normal hearing, and were paid for their services.

FIGURE 5: A block diagram of the equipment used in this study. The noise masker and the tonal signal were generated by a noise generator. The hand-pass filter limited the frequency spectrum of the noise to 100-3000 Hz. Electronic switches were used to gate both signal and noise waveforms. Attenuators were employed to control the level of both waveforms prior to their mixing. A reversing switch controlled the interaural phase of the signal (S_0 or S_π). A paper tape reader controlled the electronic switches. The combined waveforms were presented through dichotically wired earphones to four subjects seated in the sound chamber and their responses were recorded automatically.



CHAPTER THREE

RESULTS

The twelve psychometric functions obtained in this study are plotted in Figs. 6-9 for observers 1, 2, 3, and 4, respectively. In these four figures the percent correct in the 2ATFC task is plotted on the ordinate as a function of the signal-to-noise ratio expressed in decibels. The values of k , the slope of the functions which best fit the data, were 1.25 for observer 1 and 1.00 for observers 2, 3, and 4. As has been shown by Egan (1965), the slope of the psychometric functions may be considered a constant for a single observer across all conditions. The parameters for each curve are the interaural phase relations of the signal and masker ($N_0 S_0$ or $N_0 S_\pi$) and the duration of the masker.

The size of the MLD in decibels for each masker duration is obtained by measuring the lateral displacement of the appropriate $N_0 S_\pi$ function from its corresponding $N_0 S_0$ function. The MLDs obtained for each observer are plotted as a function of the masker duration in Figs. 10-13. These data are summarized in Fig. 14 in which the mean MLDs obtained for the four observers are plotted as a function of masker duration.

As can be seen in Fig. 14, as the duration of the masking noise increases from the 30 msec masker condition to the continuous masker condition, the mean MLD obtained increases from 7.50 dB to 15.50 dB. Of this total increase of eight decibels, roughly half (4.25 dB) occurs between the 30 msec and the 250 msec masker conditions. As the masker duration increases from 250 msec to 1000 msec, no significant change in the mean MLD takes place. However, in the change from the 1000 msec

FIGURE 6: Psychometric functions for observer 1 for both $N_{O}S_{O}$ and $N_{O}S_{\pi}$ for the six temporal relations investigated in this study. Each point is the mean of 400 trials. Such a point was obtained for each of two signal-to-noise ratios for each ogive. Open symbols represent the $N_{O}S_{O}$ data for a particular temporal relation. Closed symbols represent the $N_{O}S_{\pi}$ data for the same temporal relation. These ogives are for $K = 1.0$. Signal: 500 Hz, 20 msec. Method: 2ATFC.

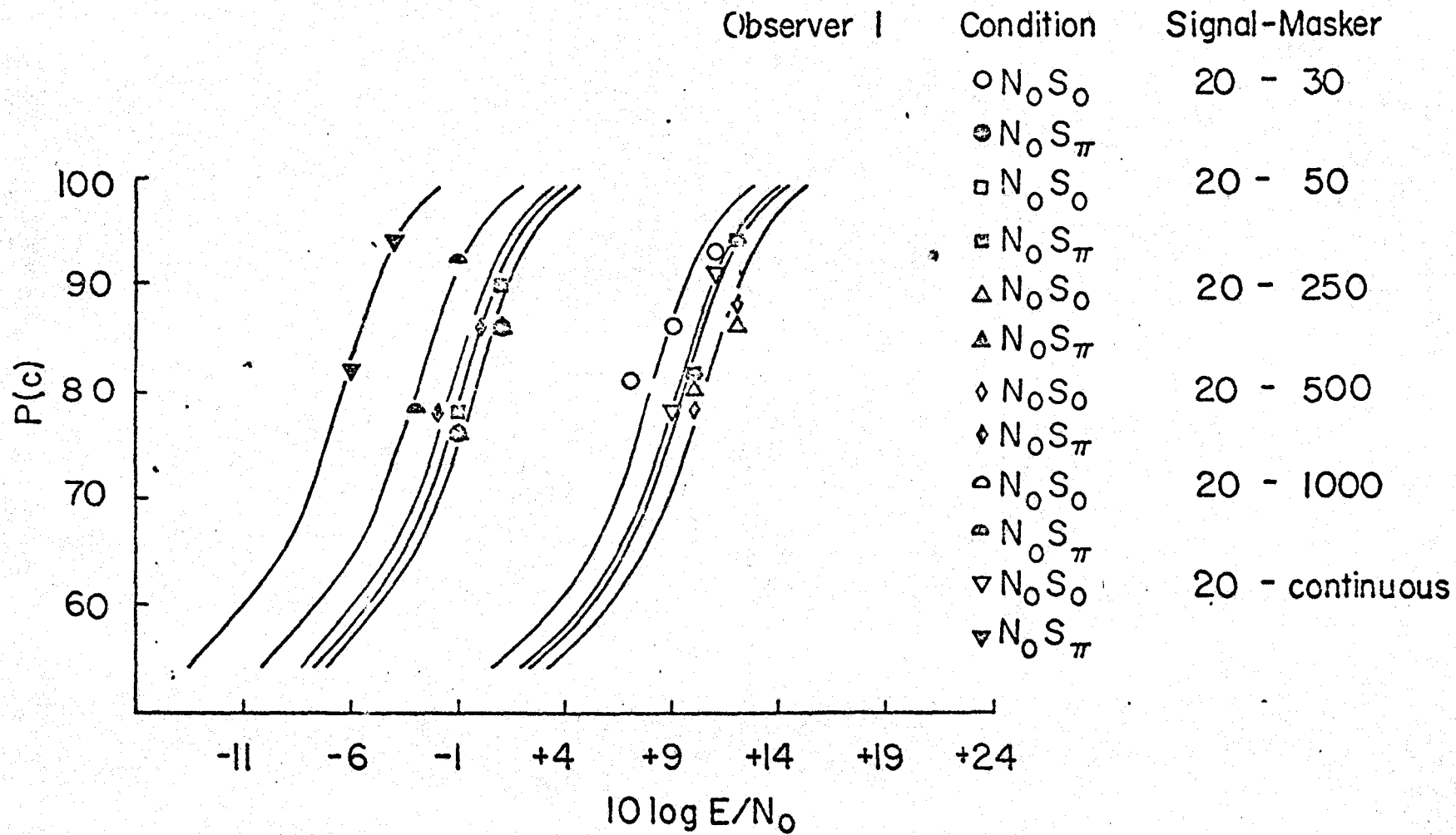


FIGURE 7: Psychometric functions for observer 2 for both $N_{O O}$ and $N_{O \pi}$ for the six temporal relations investigated in this study. Each point is the mean of 400 trials. Such a point was obtained for each of two signal-to-noise ratios for each ogive. Open symbols represent the $N_{O O}$ data for a particular temporal relation. Closed symbols represent the $N_{O \pi}$ data for the same temporal relation. These ogives are for $K = 1.25$. Signal: 500 Hz, 20 msec. Method: 2ATFC.

Observer 2

Signal-Masker

Condition

20 - 30

20 - 50

20 - 250

20 - 500

20 - 1000

20 - continuous

$\circ N_0 S_0$

$\oplus N_0 S_{\pi}$

$\square N_0 S_0$

$\blacksquare N_0 S_{\pi}$

$\triangle N_0 S_0$

$\blacktriangle N_0 S_{\pi}$

$\diamond N_0 S_0$

$\blacklozenge N_0 S_{\pi}$

$\circ N_0 S_0$

$\ominus N_0 S_{\pi}$

$\triangledown N_0 S_0$

$\blacktriangledown N_0 S_{\pi}$

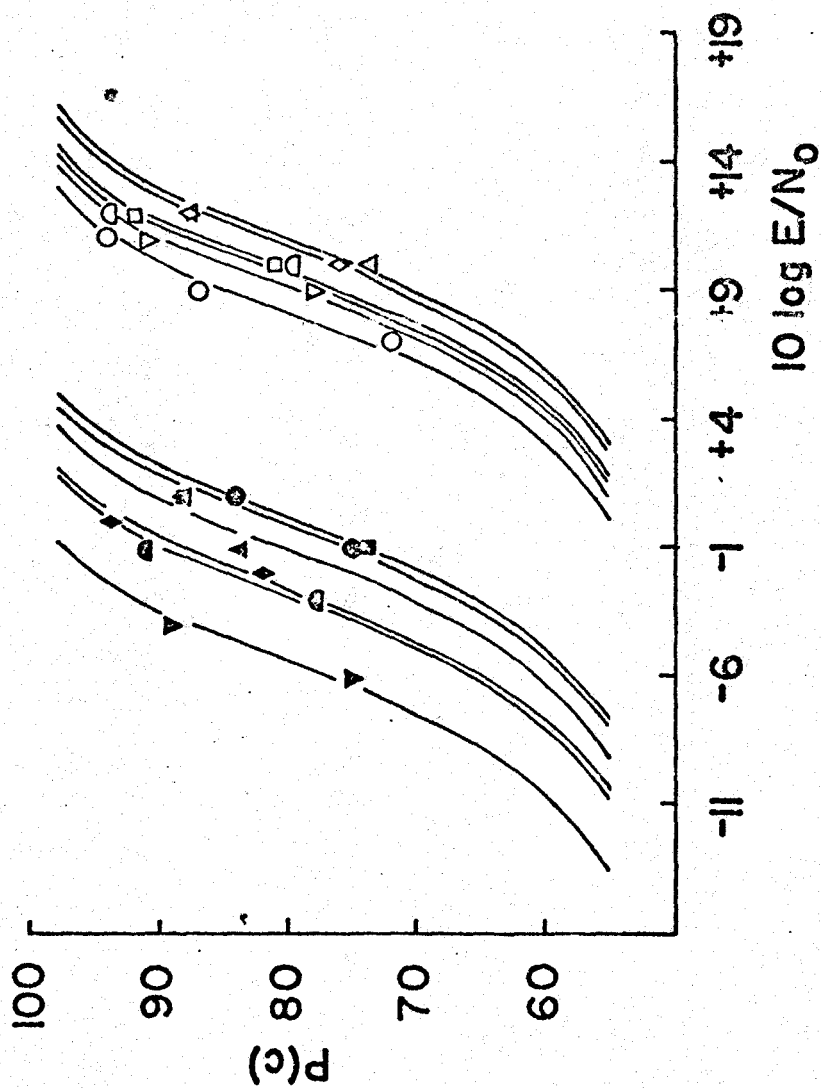


FIGURE 8: Psychometric functions for observer 3 for both $N_{O}S_{O}$ and $N_{O}S_{\pi}$ for the six temporal relations investigated in this study. Each point is the mean of 400 trials. Such a point was obtained for each of two signal-to-noise ratios for each ogive. Open symbols represent the $N_{O}S_{O}$ data for a particular temporal relation. Closed symbols represent the $N_{O}S_{\pi}$ data for the same temporal relation. These ogives are for $K = 1.25$. Signal: 500 Hz, 20 msec. Method: 2ATFC.

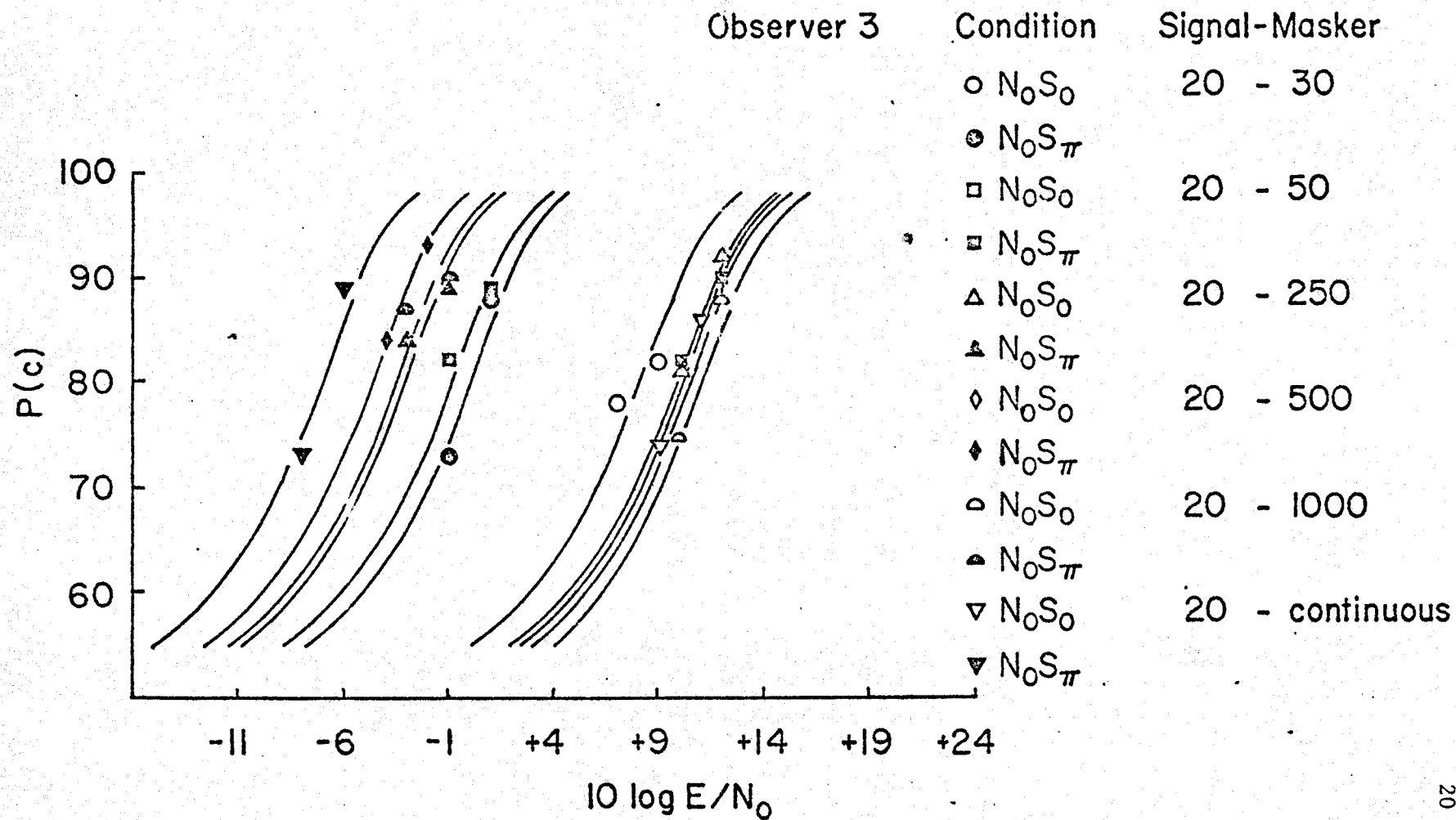


FIGURE 9: Psychometric functions for observer 4 for both $N_{O O} S_{O O}$ and $N_{O \pi} S_{O \pi}$ for the six temporal relations investigated in this study. Each point is the mean of 400 trials. Such a point was obtained for each of two signal-to-noise ratios for each ogive. Open symbols represent the $N_{O O} S_{O O}$ data for a particular temporal relation. Closed symbols represent the $N_{O \pi} S_{O \pi}$ data for the same temporal relation. These ogives are for $K = 1.25$. Signal: 500 Hz, 20 msec. Method: 2ATFC.

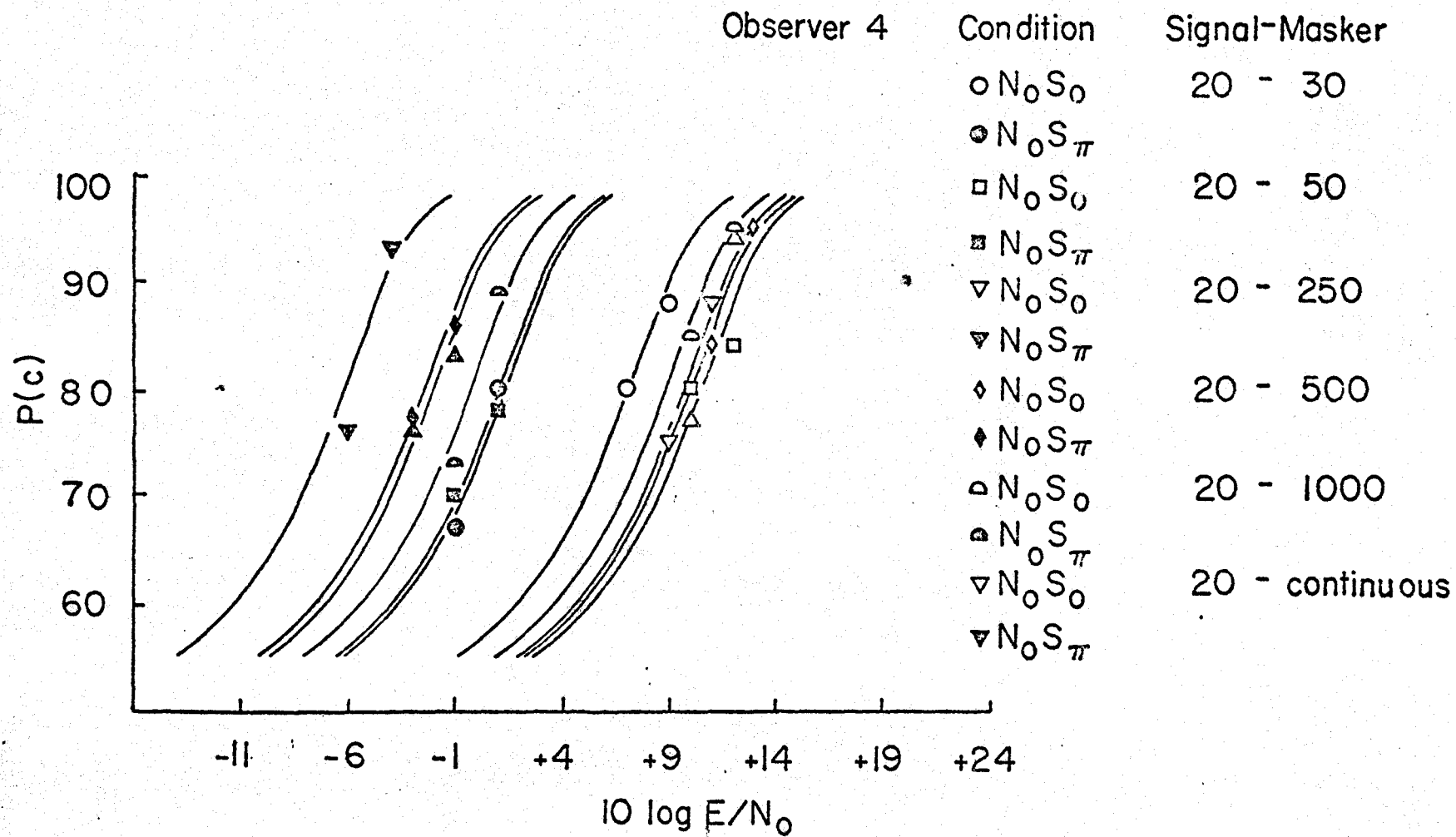


FIGURE 10: The magnitude of the MLD ($N_{O S_O}$ relative to $N_{O S_\pi}$) for observer 1 as a function of masker duration. Each point represents the magnitude of the MLD for one of the six temporal relations investigated. Magnitude of the MLD here is the lateral displacement of the ogives in Fig. 6.

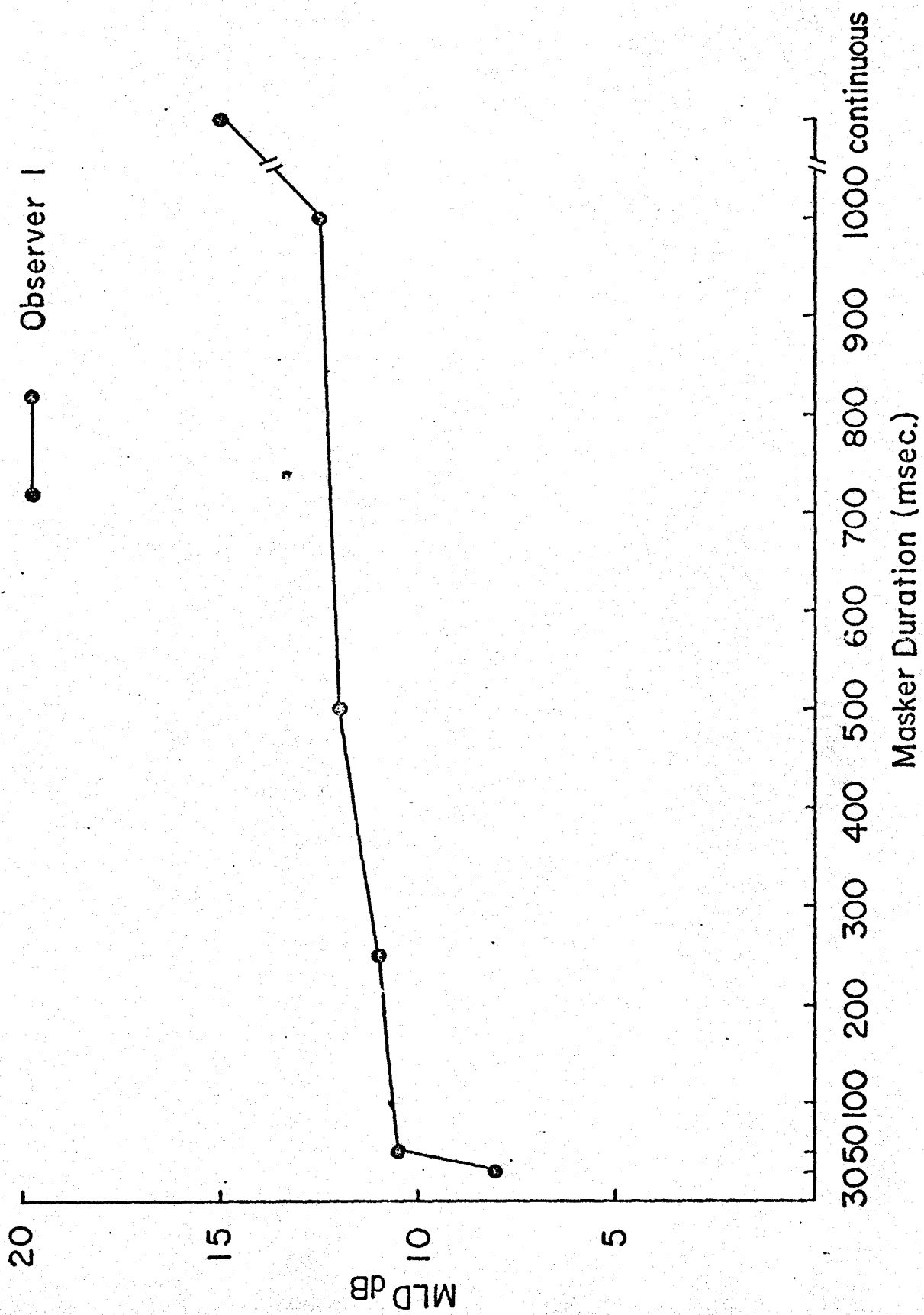


FIGURE 11: The magnitude of the MLD ($N_{O O}$ relative to $N_{O \pi}$) for observer 2 as a function of masker duration. Each point represents the magnitude of the MLD for one of the six temporal relations investigated. Magnitude of the MLD is the lateral displacement of the ogives in Fig. 7.

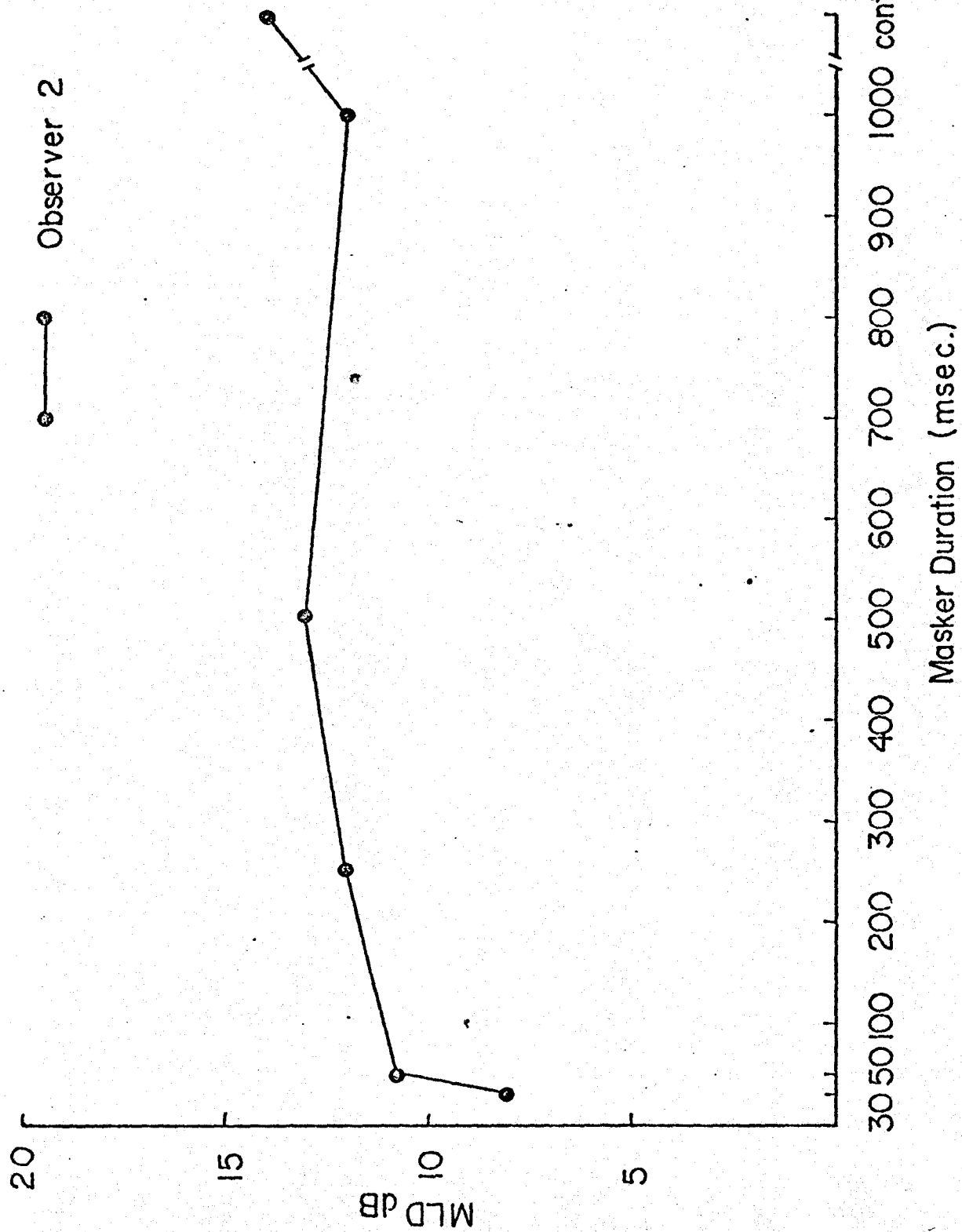


FIGURE 12: The magnitude of the MLD ($N_{O O}$ relative to $N_{O \pi}$) for observer 3 as a function of masker duration. Each point represents the magnitude of the MLD for one of the six temporal relations investigated. Magnitude of the MLD is the lateral displacement of the ogives in Fig. 8.

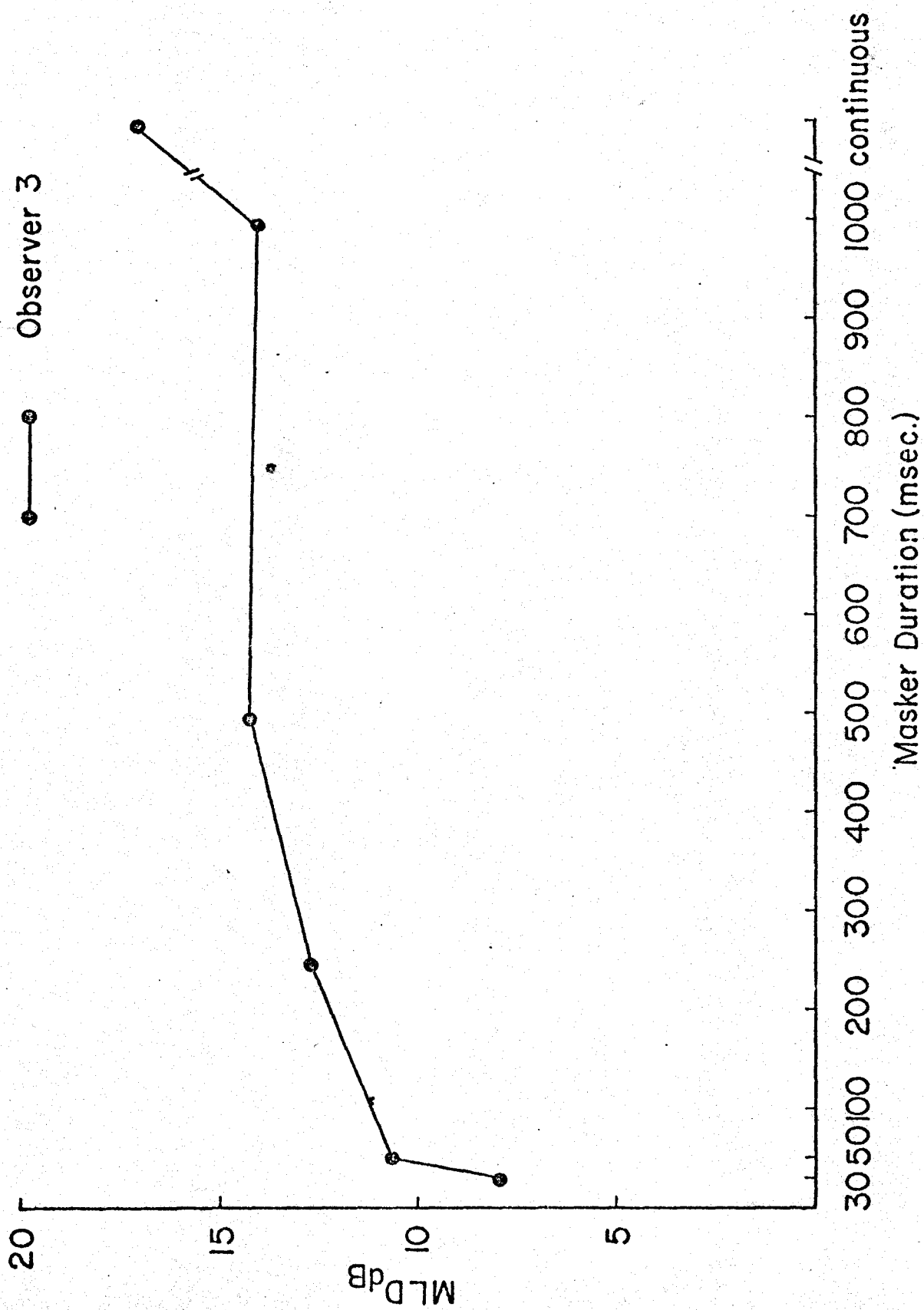


FIGURE 13: The magnitude of the MLD ($N_{O S_O}$ relative to $N_{O S_{\pi}}$) for observer 4 as a function of masker duration. Each point represents the magnitude of the MLD for one of the six temporal relations investigated. Magnitude of the MLD is the lateral displacement of the ogives in Fig. 9.

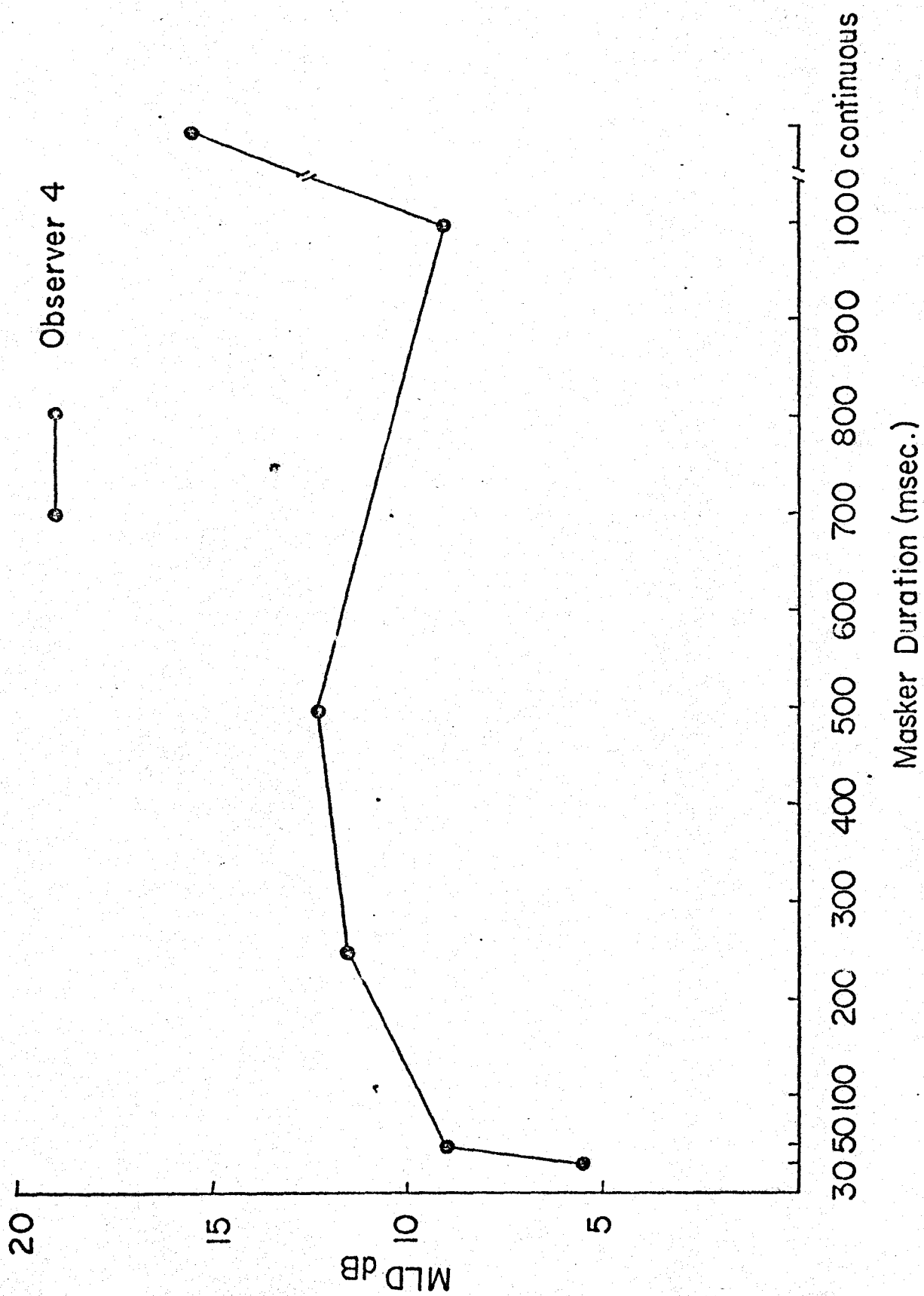
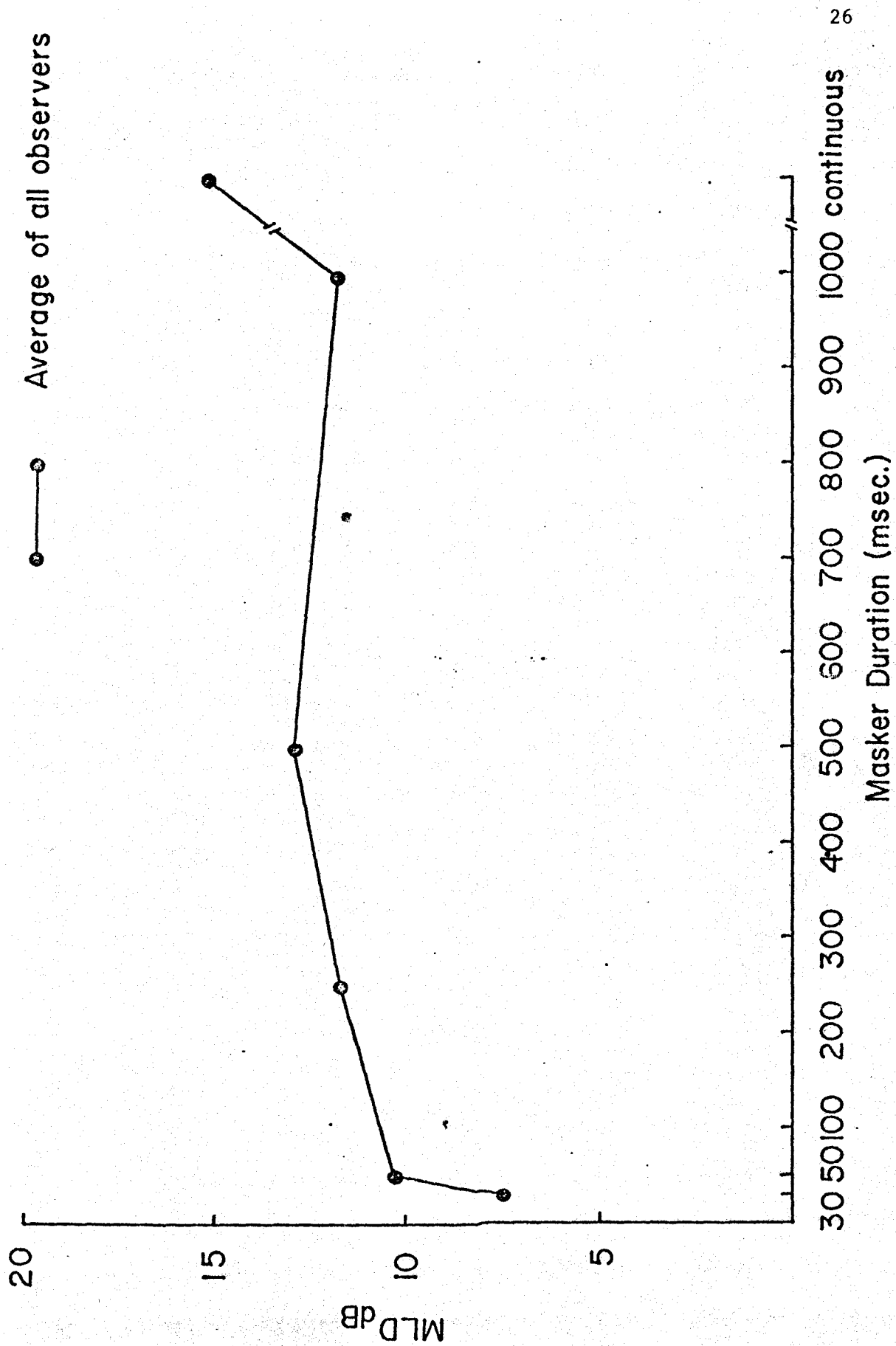


FIGURE 14: The magnitude of the mean MLD ($N_o S_o$ relative to $N_o S_{\pi}$) for the four observers as a function of masker duration. Each point represents the magnitude of the mean MLD based on the data for the four observers at one of the six temporal relations investigated.



masker condition to the continuous masker condition, the mean MLD increases 3.50 dB. Therefore, upward changes in the mean MLD take place in the transition between masker durations of 30 msec and 250 msec and also in the shift from the 1000 msec masker condition to the continuous masker condition. However, the increases in masker duration from 250 msec to 1000 msec had little effect on the mean MLD.

Since the size of the MLD is obtained by measuring the lateral displacement of the homophasic and the antiphasic psychometric functions, it is apparent that the size of the MLD can be affected by changes in the position of either the $N_{O S_O}$ or the $N_{O S_\pi}$ functions or both. In order to determine the basis for the change in the MLD obtained for each observer as masker duration was manipulated, the signal-to-noise ratio necessary for 80 percent correct detection was plotted as a function of masker duration for both interaural phase conditions. These data are presented in Figs. 15-18. Since the same ogive can be fitted rather well to all the psychometric functions for a given observer (i.e., for any given observer, all the psychometric functions are parallel), the MLD is independent of the level of performance chosen for its determination. Therefore, the vertical displacement of the $N_{O S_O}$ function from the $N_{O S_\pi}$ function in each of these figures is the MLD for that given condition. These data are summarized in Fig. 19 which presents the mean signal-to-noise ratio necessary for 80 percent correct detection for both the $N_{O S_O}$ and the $N_{O S_\pi}$ conditions as a function of masker duration.

It can be noted in Fig. 19 that as masker duration increases from 30 msec to 250 msec, there is both a small improvement in performance under the antiphasic condition and a small decrement in performance under the homophasic condition. The net effect of changes in performance in

FIGURE 15: Signal-to-noise ratio necessary for 80 percent correct detection ($N_{O O}$ and $N_{O \pi}$) for observer 1 as a function of masker duration. Each point represents the signal-to-noise ratio at which the ogives in Fig. 6 cross the 80 percent ordinate. Open symbols represent the $N_{O \pi}$ data for a particular temporal relation for a given masker duration. The vertical displacement of these points is the MLD obtained.

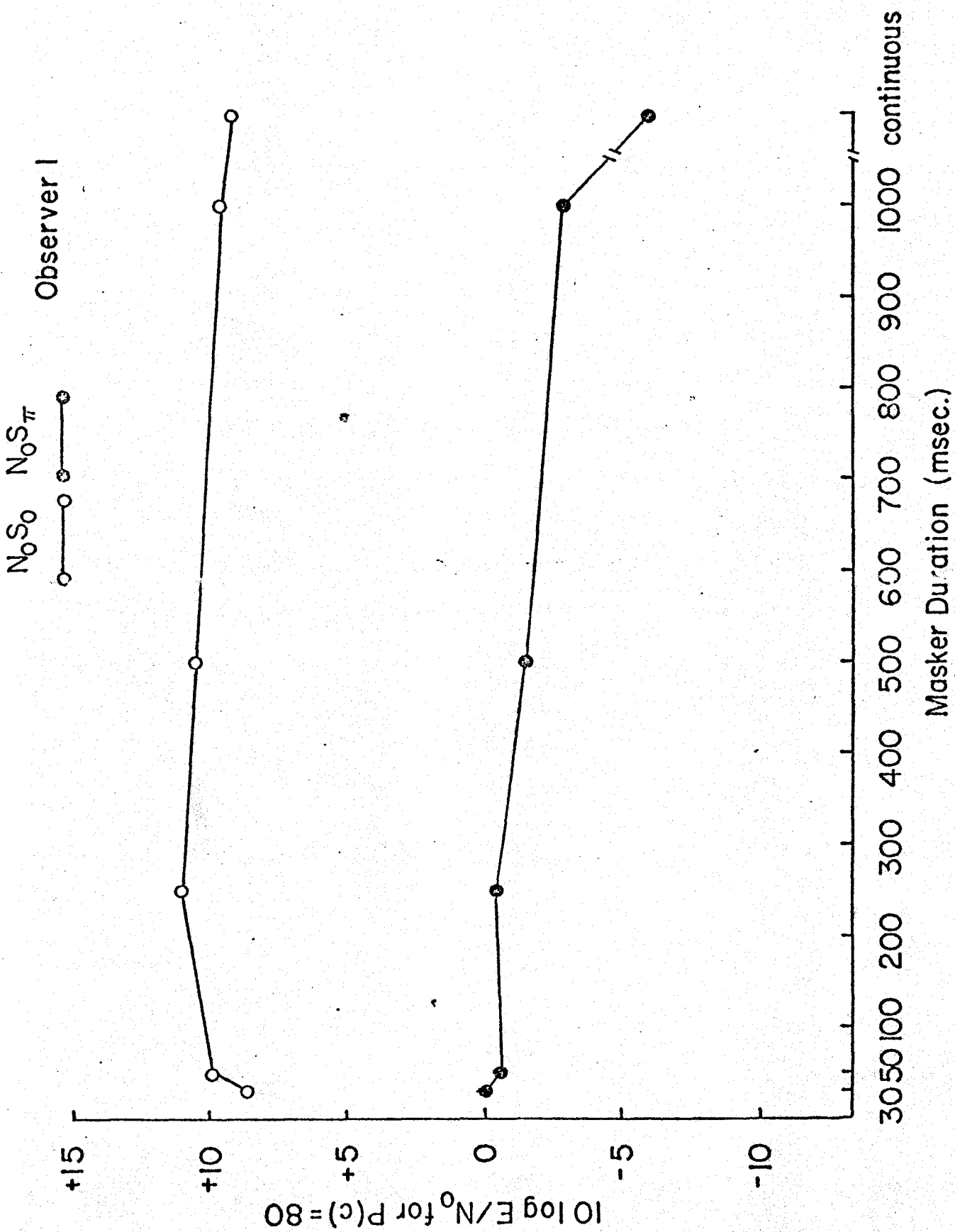


FIGURE 16: Signal-to-noise ratio necessary for 80 percent correct detection ($N_o S_o$ and $N_o S_\pi$) for observer 2 as a function of masker duration. Each point represents the signal-to-noise ratio at which the ogives in Fig. 7 cross the 80 percent ordinate. Open symbols represent the $N_o S_\pi$ data for a particular temporal relation for a given masker duration. The vertical displacement of these points is the MLD obtained.

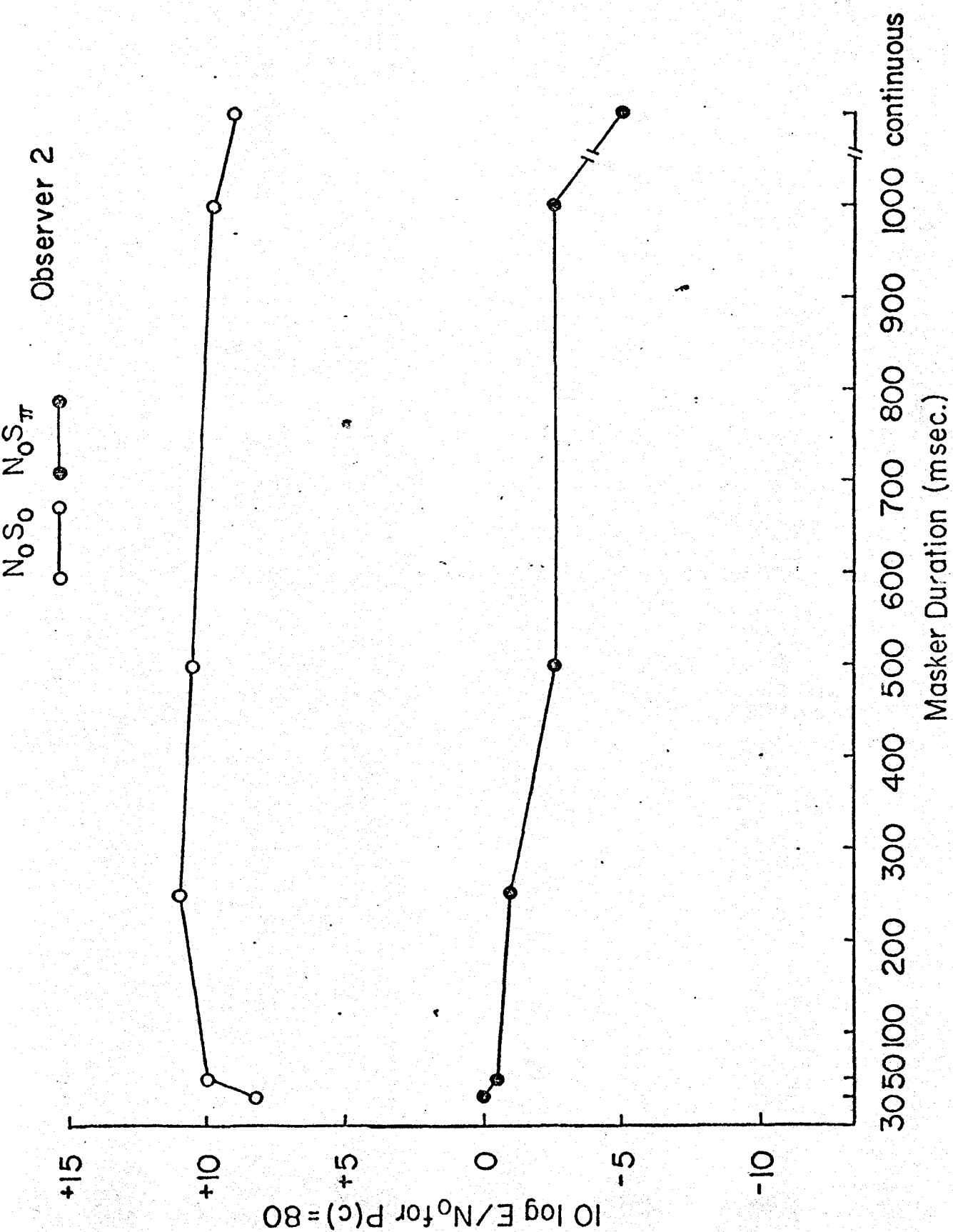


FIGURE 17: Signal-to-noise ratio necessary for 80 percent correct detection ($N_{O S_O}$ and $N_{O S_\pi}$) for observer 3 as a function of masker duration. Each point represents the signal-to-noise ratio at which the ogives in Fig. 8 cross the 80 percent ordinate. Open symbols represent the $N_{O S_\pi}$ data for a particular temporal relation for a given masker duration. The vertical displacement of these points is the MLD obtained.

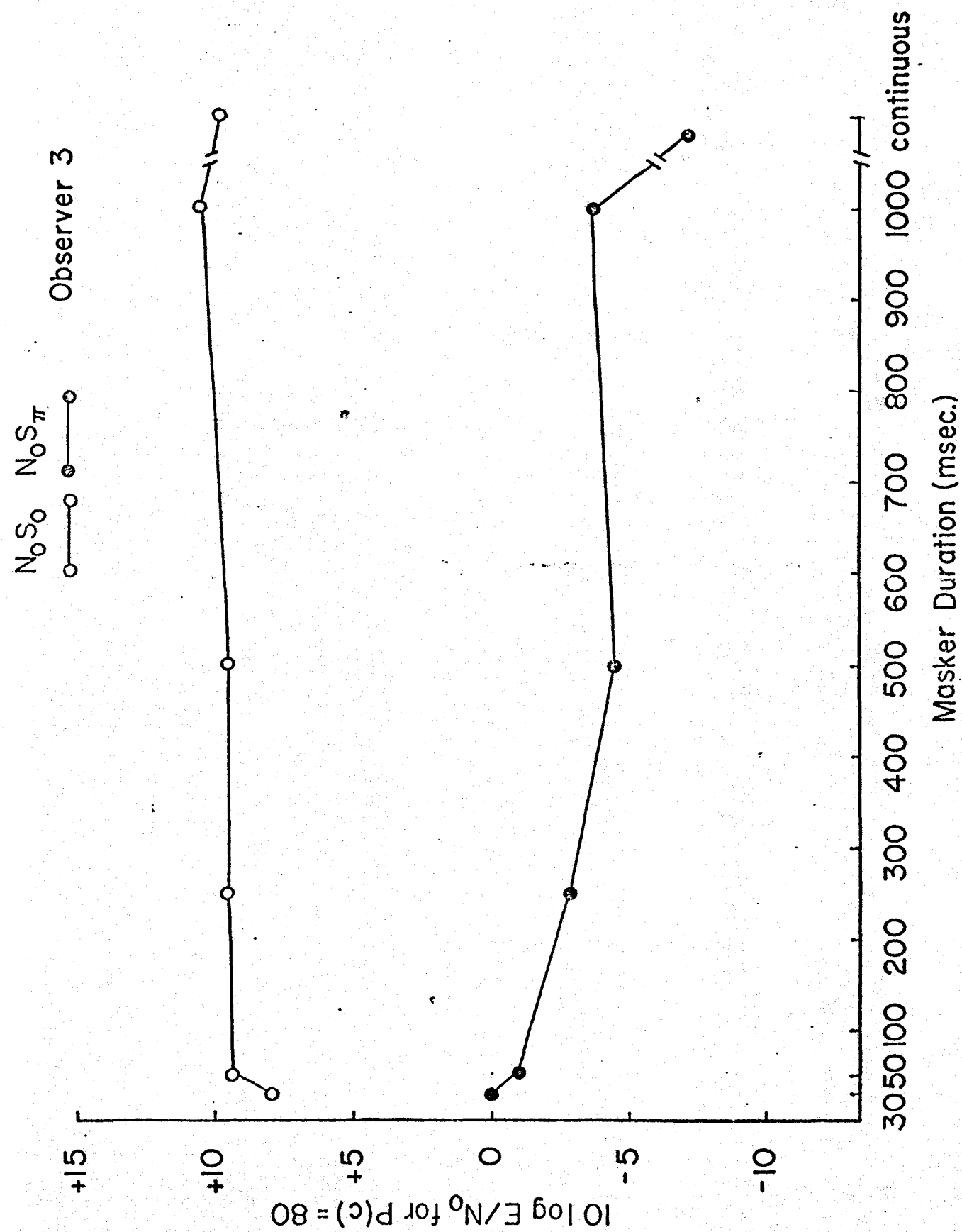


FIGURE 18: Signal-to-noise ratio necessary for 80 percent correct detection ($N_{O\ O} S_{O\ O}$ and $N_{O\ \pi} S_{O\ \pi}$) for observer 4 as a function of masker duration. Each point represents the signal-to-noise ratio at which the ogives in Fig. 9 cross the 80 percent ordinate. Open symbols represent the $N_{O\ \pi} S_{O\ \pi}$ data for a particular temporal relation for a given masker duration. The vertical displacement of these points is the MLD obtained.

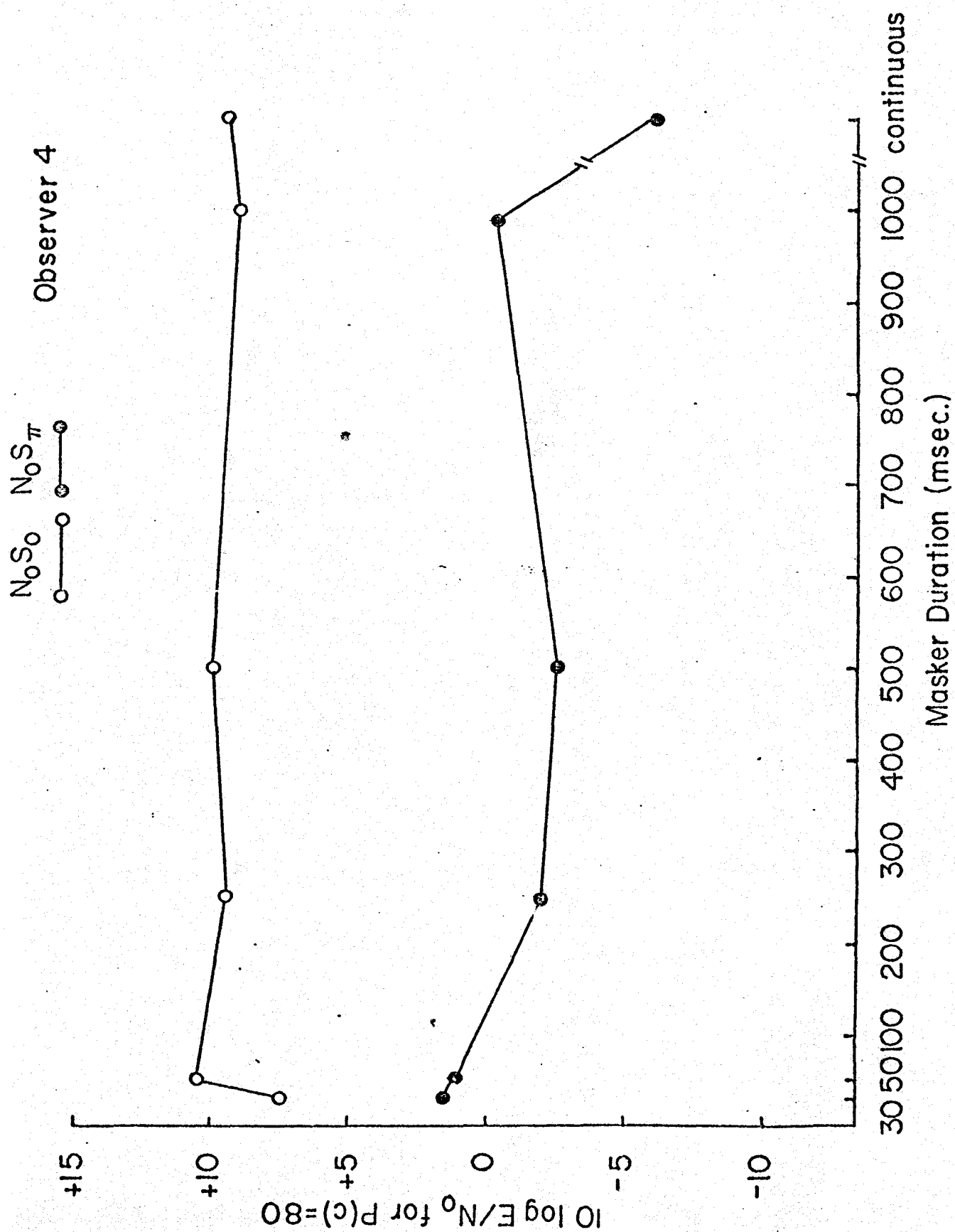
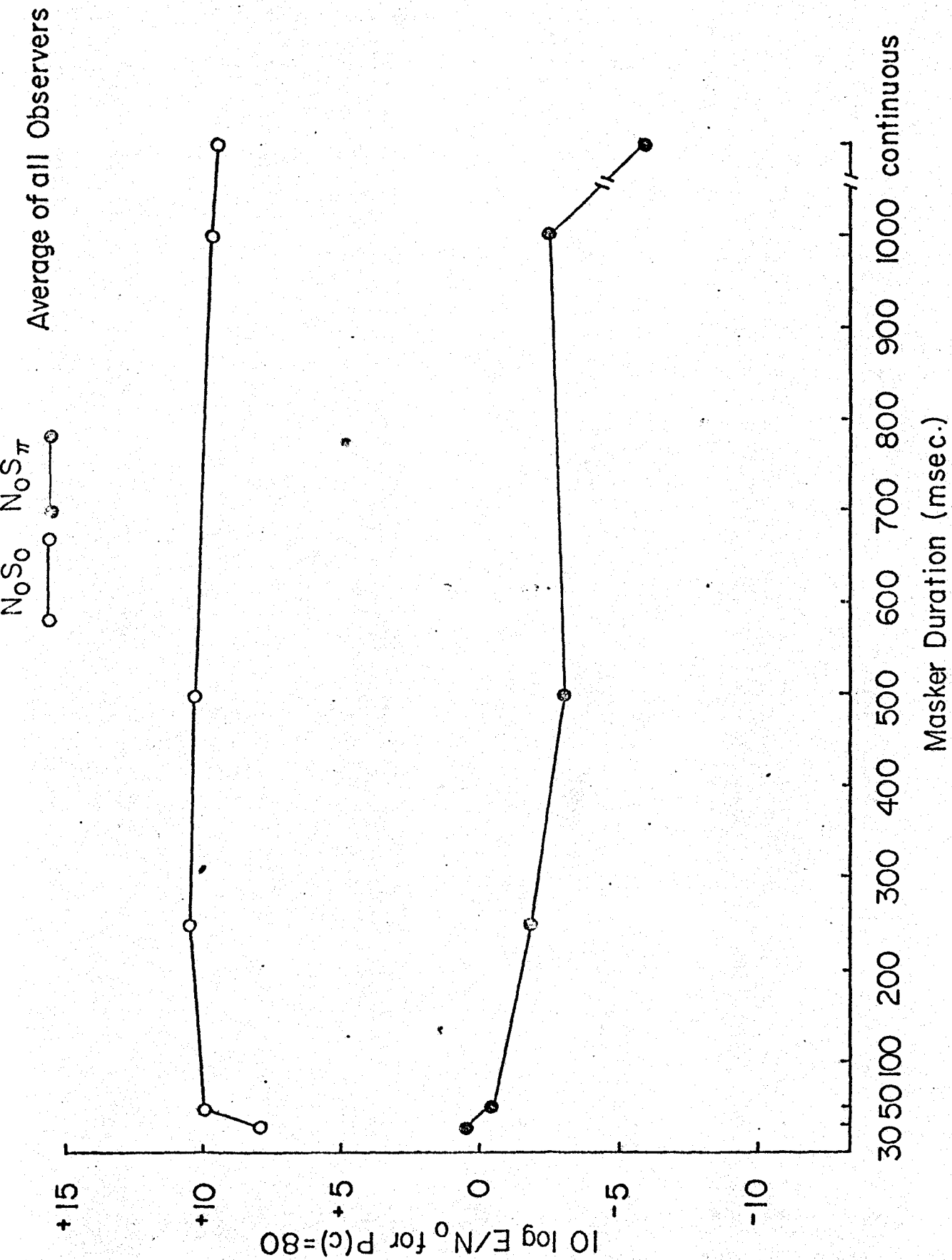


FIGURE 19: Mean signal-to-noise ratio necessary for 80 percent correct detection ($N_{O O} S_{O}$ and $N_{O \pi} S_{\pi}$) for the four observers as a function of masker duration. Each point represents the mean signal-to-noise ratio for 80 percent correct detection based on the data for the four observers at one of the six temporal relations investigated. Open symbols represent the $N_{O O} S_{O}$ data for a particular temporal relation. Closed symbols represent the $N_{O \pi} S_{\pi}$ data for a particular temporal relation.



both the homophasic and antiphasic conditions is a 4.75 dB increase in the magnitude of the MLD. On the contrary, the increase in the mean MLD between the 1000 msec and the continuous masker conditions is almost solely the result of an improvement in performance under the $N_0 S_{\pi}$ condition.

CHAPTER FOUR

DISCUSSION

In general, the results of this study indicated that the magnitude of the MLD obtained when the signal and masker onsets were simultaneous depended upon the length of time by which the offset of the masker followed the offset of the signal.

Although the effect of this backward fringe on the MLD is much like the effect of the forward fringe as reported by McFadden (1966), there are some important distinctions between the two effects. In the present study (see Fig. 14), there was little change in the mean MLD function between the 250 msec and the 1000 msec masker conditions. However, as McFadden extended his masker forward in time, the obtained MLD increased steadily until at 1000 msec of forward fringe it closely approximated the MLD obtained in the continuous masker condition. Therefore, McFadden was able to approximate the MLD obtained in the continuous masker condition by adding sufficient forward fringe to his pulsed masker. It was not possible to obtain this effect by adding backward fringe in the present study.

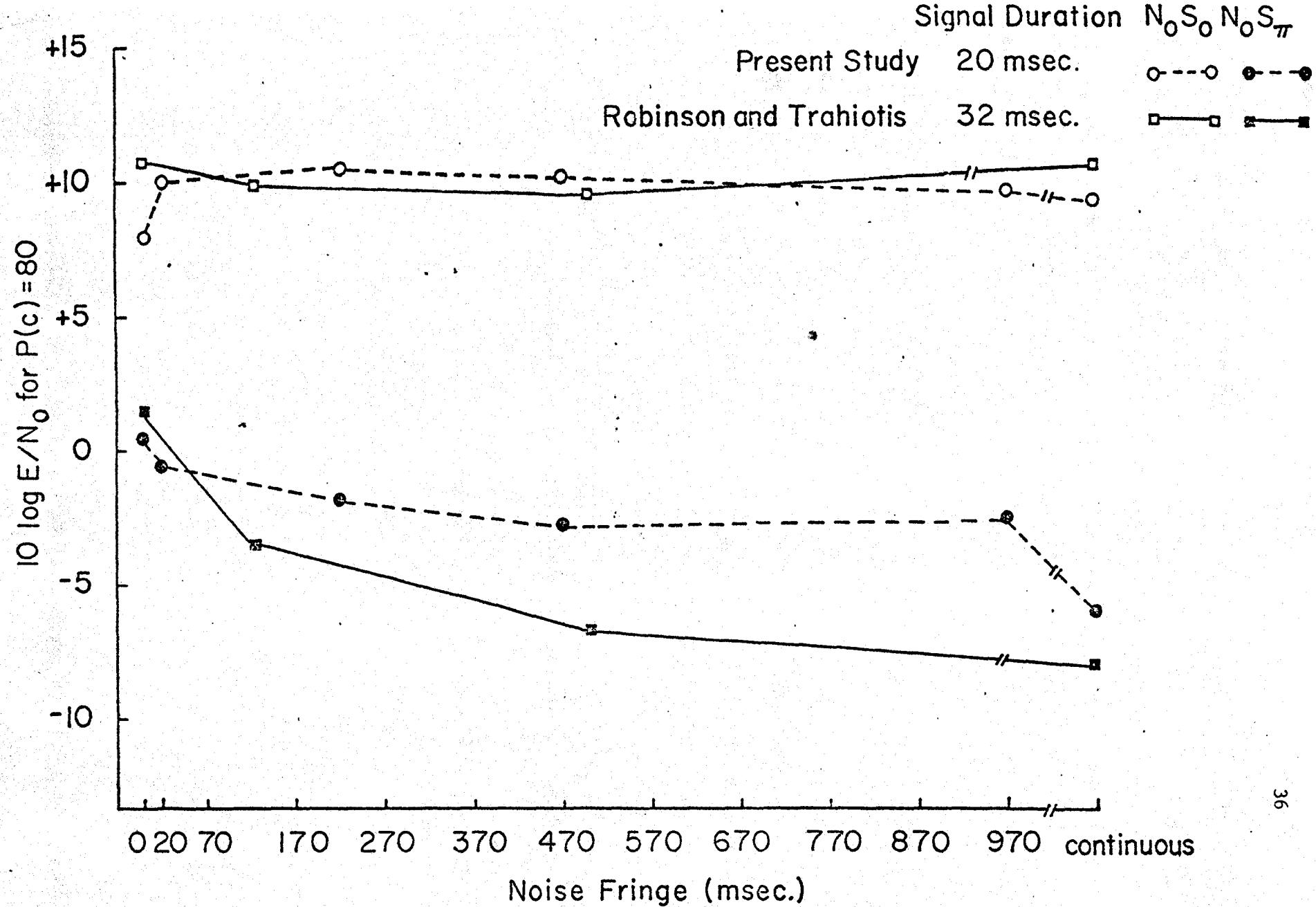
In a recent study, Robinson and Trahiotis (1971) investigated the effect of forward fringe on MLDs by masking tonal signals of various durations with pulsed noise maskers. As in the McFadden study, the offsets of the signal and masker occurred simultaneously, and the onset of the masker was moved forward in time relative to that of the signal. Their results indicated that the effects of forward fringe on the magnitude of the MLD varied as a function of signal duration. At brief signal

durations (i.e.-32 msec), the magnitude of the MLD changed considerably as the duration of forward fringe was varied. At longer signal durations (i.e.-256 msec), however, the duration of forward fringe had little effect on the magnitude of the MLD. In order to compare the magnitude of the forward fringe effect to that of the backward fringe, then, the data from the present experiment are compared to the data obtained by Robinson and Trahiotis when a brief tonal signal was employed.

In Fig. 20 the data from Fig. 19 are replotted as a function of noise fringe rather than masker duration. Thus, a masker duration of 30 msec is represented by a noise fringe of 0 msec (including the rise-fall times of the signal and noise), a masker duration of 50 msec is represented by a noise fringe of 20 msec, and so on. Also plotted in Fig. 20 are the relevant data from the Robinson and Trahiotis study.

It can be seen from the upper set of points that performance in homophasic conditions when forward fringed maskers are employed is similar to performance when backward fringed maskers are employed. The only discrepancy between the two sets of data is a 2 dB improvement in performance obtained in the 0 msec fringe condition of the present study. This 2 dB difference represents a small improvement in performance relative to other homophasic conditions when the signal and noise had simultaneous onsets and offsets. Neither McFadden (1966) nor Robinson and Trahiotis (1971) found any change in performance under homophasic conditions as a function of temporal relations of the signal and masker. Further investigation of the 30 msec and 50 msec masker duration conditions in our laboratory using three other subjects yielded results consistent with those obtained in the present study. Although this difference appears to be genuine, its causes are not clear.

FIGURE 20: Data presented in Fig. 19 replotted as a function of noise fringe along with similar data from the Robinson & Trahiotis (1971) study. The data from the present study (dotted line) are plotted as a function of backward noise fringe. Therefore, a noise fringe of 0 mask corresponds to a masker duration of 30 msec; a noise fringe of 20 msec corresponds to a masker duration of 50 msec, and so on. The data from the Robinson and Trahiotis study (solid line) are plotted as a function of forward noise fringe. Open symbols represent the data from the $N_0 S_0$ condition, while closed symbols represent the data from the $N_0 S_\pi$ condition. The signal duration for the Robinson and Trahiotis data was 32 msec.



Examination of the lower set of points in Fig. 20 indicates that performance in the antiphasic conditions seems to differ as a function of whether the fringe is in the forward or in the backward direction. As the duration of the fringe increases, performance in the forward fringe conditions becomes progressively better relative to performance in the backward fringe conditions. Additionally, performance in the forward fringe conditions approaches that obtained in a continuous masking situation as the duration of fringe increases. When the forward fringe is 500 msec, for example, the magnitude of the MLD is essentially the same as that obtained in the continuous masking situation. These results are not obtained in the backward fringe conditions. Performance in the antiphasic masking conditions only improves 3 dB as the backward fringe increases from 0 msec to 970 msec, and the magnitude of the MLD in the 970 msec backward fringe condition is considerably less than that of the MLD obtained when a continuous masker was used. This difference is indicative of the inability of backward fringe to approximate the effect of a continuous masker on the magnitude of the MLD.

In a very recent investigation of the effect of forward and backward masker fringes of correlated and uncorrelated noise on binaural signal detection, Bell (1971) found no change in performance under homophasic conditions as a function of noise fringe. This evidence casts further doubt on the 2 dB improvement in performance obtained in the present study when noise and signal onsets and offsets were simultaneous.

Bell also found that, under antiphasic conditions, as the amount of forward or backward fringe increased, detectability of the signal increased if the fringe consisted of correlated noise. This agrees with the results reported here as well as with those reported by McFadden and

those of Robinson & Trahiotis. If the masker fringe consisted of uncorrelated noise, however, no such improvement in performance was obtained.

Bell interpreted these data as supporting McFadden's explanation of forward fringe effects on the magnitude of the MLD. Bell pointed out that in the $N_0 S_\pi$ condition forward and backward fringed maskers do seem to provide a baseline or reference interaural phase since the fringe effects were present only when the noise fringe had the same phase at the two ears (i.e., was correlated).

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

The present study investigated the effects of backward masker fringe of correlated noise on performance in homophasic and antiphasic masking conditions. The results of the study indicated:

- 1) the presence of a backward masker fringe had only a small effect on performance in homophasic masking conditions;
- 2) under antiphasic masking conditions, the presence of a backward masker fringe improved performance;
- 3) similar to the results of studies investigating the effects of forward masker fringe, the magnitude of the improvement in performance increased as the duration of the fringe increased; and,
- 4) the magnitude of the improvement caused by the presence of backward masker fringe was considerably smaller than the magnitude of the improvement caused by the forward masker fringe.

It appears, then, that the presence of backward masker fringe may provide a baseline or reference phase similar to that which the forward fringe is presumed to provide. The presence of this reference phase after the offset of the signal apparently makes the phase shift associated with the signal-plus-noise waveform more discernable, thus leading to higher detectability. However, for reasons not yet clear, the presence of a baseline or reference phase after the offset of the signal (backward fringe condition) does not make the signal-plus-noise phase shift as

discernable as do either the presence of that same reference phase before the onset of the signal (forward fringe condition), or the presence of that same reference phase both before signal onset and after signal offset (continuous masker condition).

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FOOTNOTES

¹"Threshold," as used here and elsewhere in this paper, refers to the minimum sound pressure level of the signal necessary for a performance level of 75 percent in a 2ATFC task.

²Phase refers to the stage of the periodic variation of a waveform and is measured in degrees from 0 to 360 (0 to 2π radians). In Fig. 1 the changes in pressure of two sinusoids having the same frequency and amplitude are plotted during the time period from t_0 to t_1 . These sinusoids are alike in all respects except phase. At any instant from t_0 to t_1 , the pressure change of waveform a is 90 degrees ($\pi/2$ radians) behind that of waveform b. These sinusoids have a phase difference of 90 degrees.

APPROVAL SHEET

The Thesis submitted by Theodore H. Miller has been read and approved by members of the Department of Psychology.

The final copies have been examined by the director of the Thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the Thesis is now given final approval with reference to content and form.

The Thesis is, therefore, accepted in partial fulfillment of the requirements for the degree of Master of Arts.

1-17-72

Date

James R. Dolan

Signature of Advisor